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PROPOSED METHODS AND CRITERIA FOR ATCRBS PRF ASSIGNMENT.(U)

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PROPOSED METHODS AND CRITERIA FOR ATCRBS PRF ASSIGNMENT

IIT Research Institute
Under Contract to
DEPARTMENT OF DEFENSE
Electromagnetic Compatibility Analysis Center
Annapolis, Maryland 21402

August 1976

FINAL REPORT

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FEDERAL AVIATION ADMINISTRATION
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16. Abstract

A model designed to aid in selecting a pulse repetition frequency (PRF) for the Air Traffic Control Radar Beacon System (ATCRBS) has been developed by ECAC[a] for the use of the FAA. The model enables the analyst to select the best PRF from among those available for a particular site.

This report centers on a discussion of the mechanisms of near-synchronous interference and the various remedies available. Both false-target-inducing near-synchronous replies and transponder lockout are considered. Among the considerations for reducing near-synchronous interference are pulse-repetition-period separations, distance separations between sites with like PRF's, staggered and jittered PRF's, target-detection parameter adjustments, e.g., leading- and trailing-edge thresholds, range-correlation algorithms, and receiver sidelobe suppression.

Although all of the methods considered would be helpful in discriminating against near-synchronous interference, the greatest benefits are derived from maintaining at least 35 microseconds separation between pulse repetition periods for interrogator sites with overlapping service volumes.

[a]Electromagnetic Compatibility Analysis Center.

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PREFACE

The Electromagnetic Compatibility Analysis Center (ECAC) is a Department of Defense facility, established to provide advice and assistance on electromagnetic compatibility matters to the Secretary of Defense, the Joint Chiefs of Staff, the military departments and other DoD components. The Center, located at North Severn, Annapolis, Maryland 21402, is under executive control of the Assistant Secretary of Defense for Communication, Command, Control, and Intelligence and the Chairman, Joint Chiefs of Staff, or their designees, who jointly provide policy guidance, assign projects, and establish priorities. ECAC functions under the direction of the Secretary of the Air Force and the management and technical direction of the Center are provided by military and civil service personnel. The technical operations function is provided through an Air Force sponsored contract with the IIT Research Institute (IITRI).

This report was prepared for the Systems Research and Development Service of the Federal Aviation Administration in accordance with Interagency Agreement DOT-FA70WAI-175, as part of AF Project 649E under Contract F-19628-78-C-0006, by the staff of the IIT Research Institute at the Department of Defense Electromagnetic Compatibility Analysis Center.

To the extent possible, all abbreviations and symbols used in this report are taken from American Standard Y10.19 (1967) "Units Used in Electrical Science and Electrical Engineering" issued by the USA Standards Institute.

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METRIC CONVERSION FACTORS

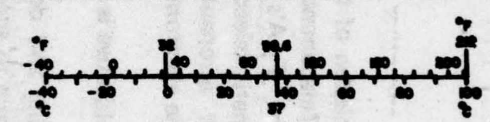
Approximate Conversions to Metric Measures

Symbol	When You Know	Multiply by	To Find	Symbol
		LENGTH		
in	inches	*2.5	centimeters	cm
ft	feet	30	centimeters	cm
yd	yards	0.9	meters	m
mi	miles	1.6	kilometers	km
		AREA		
in^2	square inches	6.5	square centimeters	cm^2
ft^2	square feet	0.09	square meters	m^2
yd^2	square yards	0.8	square meters	m^2
mi^2	square miles	2.6	square kilometers	km^2
	acres	0.4	hectares	ha
		MASS (weight)		
oz	ounces	28	grams	g
lb	pounds	0.45	kilograms	kg
	short tons (2000 lb)	0.9	tonnes	t
		VOLUME		
tsp	teaspoons	5	milliliters	ml
Tbsp	tablespoons	15	milliliters	ml
fl oz	fluid ounces	30	milliliters	ml
c	cups	0.24	liters	l
pt	pints	0.47	liters	l
qt	quarts	0.95	liters	l
gal	gallons	3.8	liters	l
ft^3	cubic feet	0.03	cubic meters	m^3
yd^3	cubic yards	0.76	cubic meters	m^3
		TEMPERATURE (exact)		
°F	Fahrenheit temperature	5/9 (after subtracting 32)	Celsius temperature	°C

*1 in = 2.54 (exactly). For other exact conversions and more detailed tables, see NBS Misc. Publ. 286, Units of Weights and Measures, Price $2.25, SD Catalog No. C13.10:286.

Approximate Conversions from Metric Measures

Symbol	When You Know	Multiply by	To Find	Symbol
		LENGTH		
mm	millimeters	0.04	inches	in
cm	centimeters	0.4	inches	in
m	meters	3.3	feet	ft
m	meters	1.1	yards	yd
km	kilometers	0.6	miles	mi
		AREA		
cm^2	square centimeters	0.16	square inches	in^2
m^2	square meters	1.2	square yards	yd^2
km^2	square kilometers	0.4	square miles	mi^2
ha	hectares (10,000 m^2)	2.5	acres	
		MASS (weight)		
g	grams	0.035	ounces	oz
kg	kilograms	2.2	pounds	lb
t	tonnes (1000 kg)	1.1	short tons	
		VOLUME		
ml	milliliters	0.03	fluid ounces	fl oz
l	liters	2.1	pints	pt
l	liters	1.06	quarts	qt
l	liters	0.26	gallons	gal
m^3	cubic meters	35	cubic feet	ft^3
m^3	cubic meters	1.3	cubic yards	yd^3
		TEMPERATURE (exact)		
°C	Celsius temperature	9/5 (then add 32)	Fahrenheit temperature	°F



FEDERAL AVIATION ADMINISTRATION
SYSTEMS RESEARCH AND DEVELOPMENT SERVICE
SPECTRUM MANAGEMENT STAFF

STATEMENT OF MISSION

The mission of the Spectrum Management Staff is to assist the Department of State, Office of Telecommunications Policy, and the Federal Communications Commission in assuring the FAA's and the nation's aviation interests with sufficient protected electromagnetic telecommunications resources throughout the world to provide for the safe conduct of aeronautical flight by fostering effective and efficient use of a natural resource--the electromagnetic radio-frequency spectrum.

This objective is achieved through the following services:

- Planning and defending the acquisition and retention of sufficient radio-frequency spectrum to support the aeronautical interests of the nation, at home and abroad, and spectrum standardization for the world's aviation community.

- Providing research, analysis, engineering, and evaluation in the development of spectrum related policy, planning, standards, criteria, measurement equipment, and measurement techniques.

- Conducting electromagnetic compatibility analyses to determine intra/inter-system viability and design parameters, to assure certification of adequate spectrum to support system operational use and projected growth patterns, to defend the aeronautical services spectrum from encroachment by others, and to provide for the efficient use of the aeronautical spectrum.

- Developing automated frequency-selection computer programs/routines to provide frequency planning, frequency assignment, and spectrum analysis capabilities in the spectrum supporting the National Airspace System.

- Providing spectrum management consultation, assistance, and guidance to all aviation interests, users, and providers of equipment and services, both national and international.

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SECTION 1

INTRODUCTION

BACKGROUND

One area of the continuing effort by the Federal Aviation Administration (FAA) to upgrade the performance of the Air Traffic Control Radar Beacon System (ATCRBS) is in the assignment of pulse repetition frequencies (PRF's). Because of the large number of interrogators and the limited number of available PRF's, the problem of PRF assignment has become increasingly complex. For this reason, the FAA tasked ECAC to develop techniques and criteria for PRF assignment that would enable the FAA to minimize the effects of near-synchronous interference.

The FAA determined that there was a need for a prediction model that would guide analysts in the selection of the best PRF from among those available for a particular site. The FAA was also interested in obtaining some basic guidelines for PRF assignment such as required distance separations for sites with similar PRF's, and separations in pulse repetition periods for sites within the same coverage area. In addition, an investigation was desired of the advantages of staggered and jittered PRF's, along with other remedies for near-synchronous interference.

OBJECTIVE

To develop basic guidelines for ATCRBS PRF assignment and to develop an automated PRF selection process.

APPROACH

To establish basic guidelines for PRF assignment, it was necessary to investigate the types of interference that result from improperly

assigned PRF's. Both the interrogation link and the reply link were analyzed for the impact of near-synchronous interference on ATCRBS performance. The ability of several types of processors to discriminate against near-synchronous replies was considered, and the impact of transponder lockout on the performance of the ground system was assessed.

Two critical parameters were selected as a starting point for suitable PRF assignment. These were the separation between pulse repetition periods (PRP's) for interrogators within the same coverage area, and the required distance separation between interrogator sites with the same PRF. These are considered the basic criteria for optimal PRF assignment.

A major obstacle to the development of useful PRF assignment criteria was the lack of available information concerning the ability of FAA processing equipment to discriminate against near-synchronous interference. A test program was undertaken at NAFEC[a], the FAA experimental center in Atlantic City, to evaluate the performance of both FAA defruiting equipment and statistical processors in the presence of near-synchronous interference. This test program was accomplished as part of an effort to develop models of FAA processing equipment for use with the ECAC ATCRBS prediction models.[1] The information obtained from those tests was also used to support the analysis described in this report.

The purpose of developing the PRF selection model was to create an automated PRF selection process that would allow the user to quickly select the best PRF from among those that are available for a particular interrogator site, given that the basic criteria cannot be met. The number of PRF's available is normally limited by the PRF of the primary

---

[a]National Aviation Facilities Experimental Center.

[1]Crawford, C. R., *Computer Simulations of ATCRBS Processing Equipment for Use with the AIMS and Transient Effects PPM's*, FAA-RD-76-102, ECAC, Annapolis, MD, January 1976.

radar, since the beacon PRF is usually a submultiple of that value. In keeping with the above-stated purpose, a model was developed that evaluates the mathematical relationships between the PRF's and the transponder dead-time, compares the performance of one PRF to that of another, and selects the PRF that results in the least interference. Section 4 contains a description of the model, complete with a discussion of simplifying assumptions, approach, and program flow.

The work under this project was performed during the period from 1974 to 1975.

SECTION 2

SYSTEM DESCRIPTION

GENERAL

The FAA air traffic surveillance system (ATCRBS)[a] and the military identification system (AIMS)[b] operate on 1030-and 1090 MHz as illustrated in Figure 1. The ATCRBS and the AIMS usually operate in conjunction with the primary surveillance radar, with the interrogator transmitting coded interrogations on 1030 MHz. The transponder-equipped aircraft receives the interrogations, decodes them, deactivates its receiver after each decode, transmits a reply on 1090 MHz, and then reactivates its receiver in preparation for another interrogation. The interrogator's receiver system receives replies, processes them, and displays the targets on a radar plan position indicator (PPI).

NEAR-SYNCHRONOUS INTERFERENCE

Interrogations are transmitted at a rate equal to, or at a submultiple of, the primary radar trigger rate. For those interrogators operating independently of a primary radar, the interrogation rate is determined by an internal or external trigger source. When the PRF's of interrogators covering the airspace are improperly assigned, *near-synchronous* interference results. Replies from a transponder that is responding to interrogations from a given interrogator will arrive at that interrogator at the same relative time each PRF period. These are synchronous replies and they form the target image at a particular range on the PPI. Replies to interrogations from other interrogators do not always arrive at the same time during the PRF period of a victim interrogator. These are

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[a]Air Traffic Control Radar Beacon System.

[b]ATCRBS IFF Mark XII System.

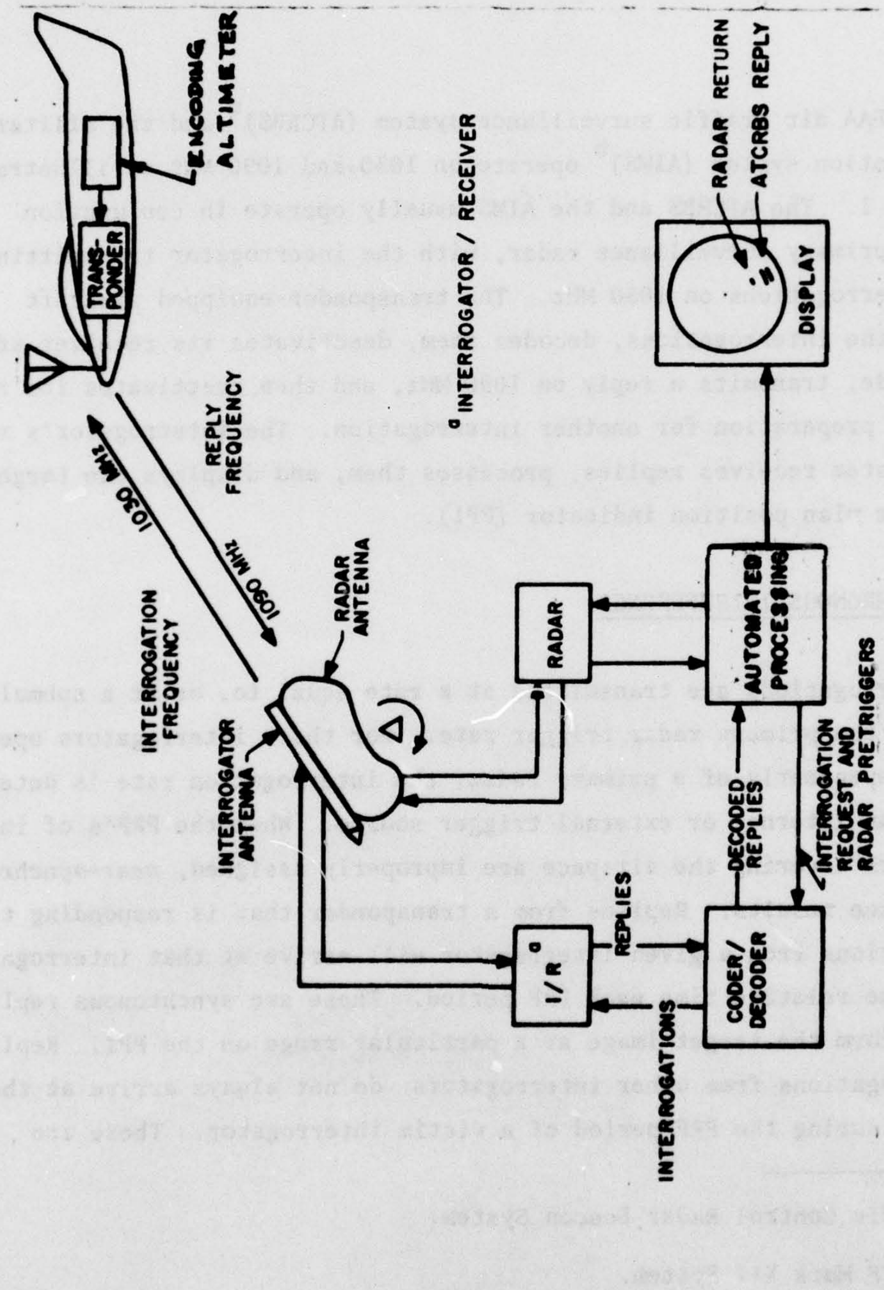

Figure 1. General configuration of ATCRBS equipments.

non-synchronous replies (fruit) received generally from all transponders in a given environment and they will, if PRF's are suitably assigned, appear distributed in range with no apparent pattern on the PPI. If PRF's are separated by a sufficient amount, fruit replies will not form a distinctive pattern on the PPI, and defruiters and statistical processors can eliminate most of them. When the PRF separation is not sufficient, the fruit replies will form distinct patterns on the PPI, as shown in Figure 2. In addition to the strobes and spirals shown in the figure, false targets can occur which can make it difficult to identify true target returns.

Another type of near-synchronous interference can affect transponder reply capability. Less-than-perfect performance is inherent in ATCRBS operation because transponder receiver shut-down, after recognition of a valid pulse-pair, prevents replies to interrogations that arrive during the resulting *deadtime*. With proper PRF separation, this interference occurs rarely. However, if the transponder receives interrogations from two or more interrogators with identical PRF's, and if the arrival times of the interrogations from some of these ground interrogator facilities are within the transponder deadtime, the transponder will reply to one interrogator (the first received) and not to the others. This will continue to occur as long as the transponder is within range of more than one interrogator having identical PRF's. This type of near-synchronous interference is termed *transponder lockout*. The near-synchronization of the interrogation arrival times will cause missed replies to a series of interrogations and result in failure to display a target or the display of a false target. This type of interference will occur between interrogators with approximately the same PRF and between interrogators having PRF's that are multiples of one another.

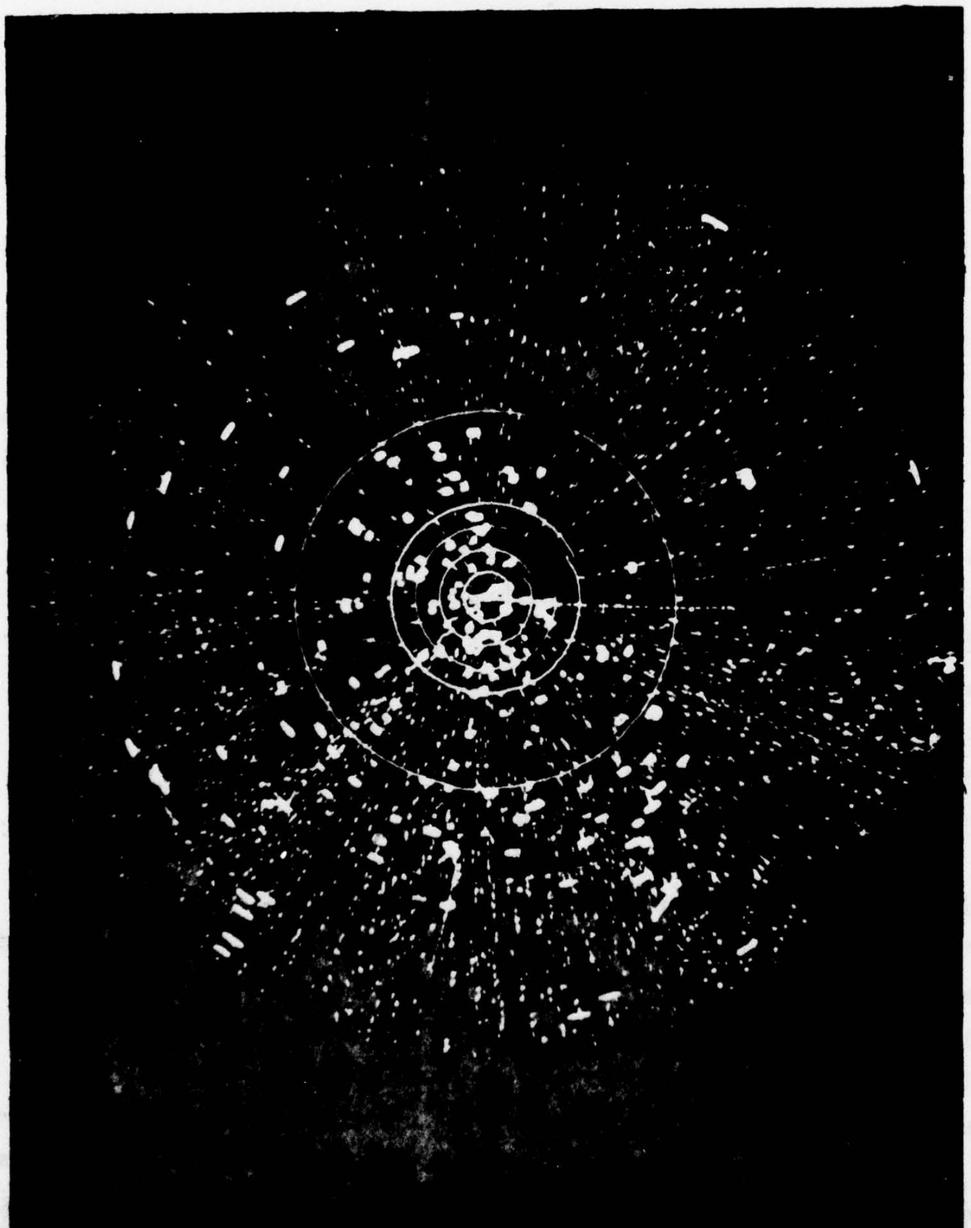

Figure 2. Near-synchronous interference, PPI display.

Transponder lockout, or capture, can occur in two ways. First, a valid interrogation may lock out another valid interrogation. The interfering interrogation could come from the mainbeam of an interrogator equipped with transmitter sidelobe suppression or from any lobe of the antenna pattern of an interrogator not equipped with transmitter sidelobe suppression. If the first interrogation pulses from two or more ground interrogators arrive at a transponder within the deadtime period, then lockout of the second interrogator (or other interrogators) will occur. The longest allowable transponder deadtime for a mode 3/A interrogation is approximately 160 μs; this includes the interrogation length (8 μs), the transponder delay (3 μs), the reply lengths (21 - 25 μs), and the maximum allowable deadtime after the last reply pulse is transmitted (125 μs).[2]

A second way that transponder lockout can occur is when a transmitter sidelobe suppression signal (from a ground interrogator) locks out a valid mainbeam interrogation. In this case the longest allowable deadtime is approximately 47 μs. This includes the sidelobe suppression coding (2 μs) and the suppression time (≈ 25 to 45 μs).[2]

The FAA now has seven PRF's available for the en route ATCRBS. These are 340, 345, 350, 355, 360, 365, and 370. For FAA terminal sites the PRF's are counted down from the airport surveillance radar (ASR) PRF in the following manner:

ASR-3:	1030, 1050, 1070 divided by 3
ASR-4, 5, 6:	1200, 1170, 1140 divided by 3 or 4
ASR-7:	8-way stagger
ASR-8:	340 - 325 in 1% steps (fixed PRF); radar PRF staggered.

[2]*U.S. National Standard for the IFF MARK X (SIF) ATCRBS Characteristics*, FAA Order 1010.51A, Federal Aviation Administration, Washington, DC, 8 March 1971.

Delay lines are being obtained to provide some additional PRF's, but the limited number of PRF's available makes some degree of near-synchronous interference unavoidable.

Staggering of PRF's is a technique that was originally developed to deal with the problems of next-sweep ("second-time-around") targets. Staggering is a method of transmission by which the pulse repetition period (PRP) or the time interval between interrogations, is varied in a repetitive sequence. That is, an 8-way stagger, such as that used by ASR-7 sites, consists of eight interrogations separated by variable time periods, which are then continuously repeated in the same pattern.

Another method of altering the nominal PRP is to jitter the interrogation rate. Jittering is usually accomplished by randomly changing the pulse repetition period by a few microseconds over a stepped sequence. For instance, with a pulse repetition period of 2700 μs, the jitter would be introduced randomly to generate with equal probability a period of either 2700, 2701.5 or 2703 μs, assuming a jitter of 0, 1.5, or 3 μs.

SECTION 3
ANALYSIS

INTRODUCTION

Near-synchronous interference resulting from improperly assigned PRF's can be of two types. The first can be termed *downlink* interference and the second, *uplink* interference.

Downlink interference consists of those fruit replies which, upon being received by a victim interrogator, are nearly *synchronous* with the pulse repetition period of the victim. These near-synchronous replies can group together to form a false target or can overlap sychronous replies to garble a valid target. The ability to discriminate against downlink interference is determined by the type of processor used with the beacon.

Uplink interference creates the problem of transponder lockout. The deadtime gate in the transponder together with interfering interrogations comprise the mechanism for this type of interference. The interfering interrogator *captures* the transponder for a period of time during which the victim interrogator will receive no replies. The length of these miss strings is dependent upon the degree of separation between the PRP's of the two interrogators and the deadtime of the transponder. The impact of miss strings of a certain length is dependent again upon the type of processor associated with the victim interrogator.

DOWNLINK INTERFERENCE

The basic beacon processors that are considered here are the defruiter/decoder system, the ARTS[a] III with defruited and undefruited input, and

[a]Automated Radar Terminal System.

the en route system common digitizer. The AN/TPX-42 and the ARTS II statistical processors are not considered in this analysis. The defruiter/decoder system is used primarily as a backup for the ARTS III at terminal locations and for the common digitizer at en route sites.

Defruiter/Decoder Systems

The function of the defruiter in the ATCRBS is to filter out asynchronous pulses and pass only valid synchronous pulses to the decoder. The defruiter is connected between the interrogator-receiver video output and the video input to the decoder unit. The defruiter passes to the decoder only those pulses that are in coincidence with pulses received on the last interrogation of the same mode (Reference 2). Coincidence detection is accomplished on a pulse-by-pulse basis.

Figure 3 illustrates the operation of the defruiter acceptance gate. The acceptance gate is approximately ±1 μs from the leading-edge of the stored video pulse. However, it is misleading to assume that separating the PRP's of a pair of interrogators by more than 1 μs will enable the defruiter to eliminate mutual near-synchronous interference. Figure 4 demonstrates the pulses that can pass on to further decoding when the PRP's of two interrogators are separated by 10 μs. The ATCRBS reply code is 5624 for this case, and the coincidence detector in the defruiter operates with an acceptance gate of ±1 μs, passing pulses C_2 and A_4 of the reply train on to further decoding. It can be seen in Figure 4 that the delay of 10 μs in receipt of the reply to the second interrogation causes pulse C_2 of the incoming video to fall within the acceptance gate set up by pulse B_2 of the stored video. Pulse B_2 is stored 14.5 μs after the leading edge of the first framing pulse. Pulse C_2 is transmitted by the transponder 4.35 μs after pulse F_1, and a delay of 10 μs causes

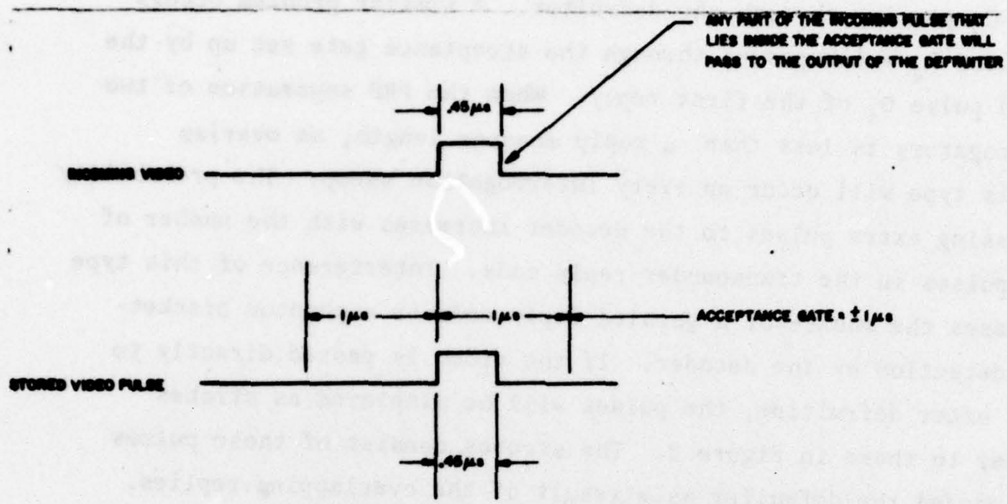

Figure 3. Defruiter acceptance gate.

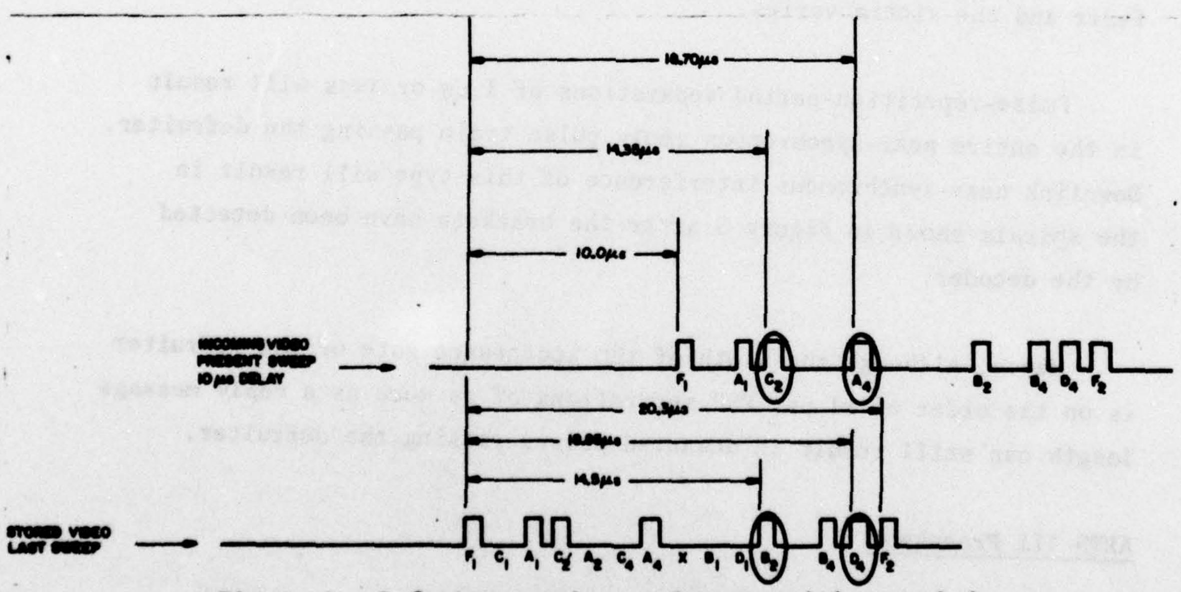

Figure 4. Defruiter action, pulse-repetition-period separation of 10 µs.

C_2 to fall 14.35 μs after the stored pulse F_1, thus resulting in pulse C_2 passing through the defruiter. A similar problem occurs for pulse A_4 which passes through the acceptance gate set up by the stored pulse D_4 of the first reply. When the PRP separation of two interrogators is less than a reply message length, an overlap of this type will occur on every interrogation sweep. The probability of passing extra pulses to the decoder increases with the number of code pulses in the transponder reply code. Interference of this type increases the chance of a garbled reply code or a phantom bracket-pair detection by the decoder. If the video is passed directly to a PPI after defruiting, the pulses will be displayed as strobes similar to those in Figure 2. The strobes consist of those pulses that passed the defruiter as a result of the overlapping replies. The apparent range of the pulses generates the strobes as the difference in arrival time between the replies generated by the interferer and the victim varies.

Pulse-repetition-period separations of 1 μs or less will result in the entire near-synchronous reply pulse train passing the defruiter. Downlink near-synchronous interference of this type will result in the spirals shown in Figure 5 after the brackets have been detected by the decoder.

Hence, although the width of the acceptance gate of the defruiter is on the order of ±1 μs, PRP separations of as much as a reply message length can still result in unwanted pulses passing the defruiter.

ARTS III Processor

At most FAA interrogator sites, the ARTS III processor operates on defruited video. The purpose of the defruiter in that configuration is to filter out non-synchronous pulses which degrade the code validation capabilities of the ARTS. However, since defruiter action

increases the number of missing replies, its use may degrade target detection and code validation capability. The problem of missing replies will be discussed later in this section.

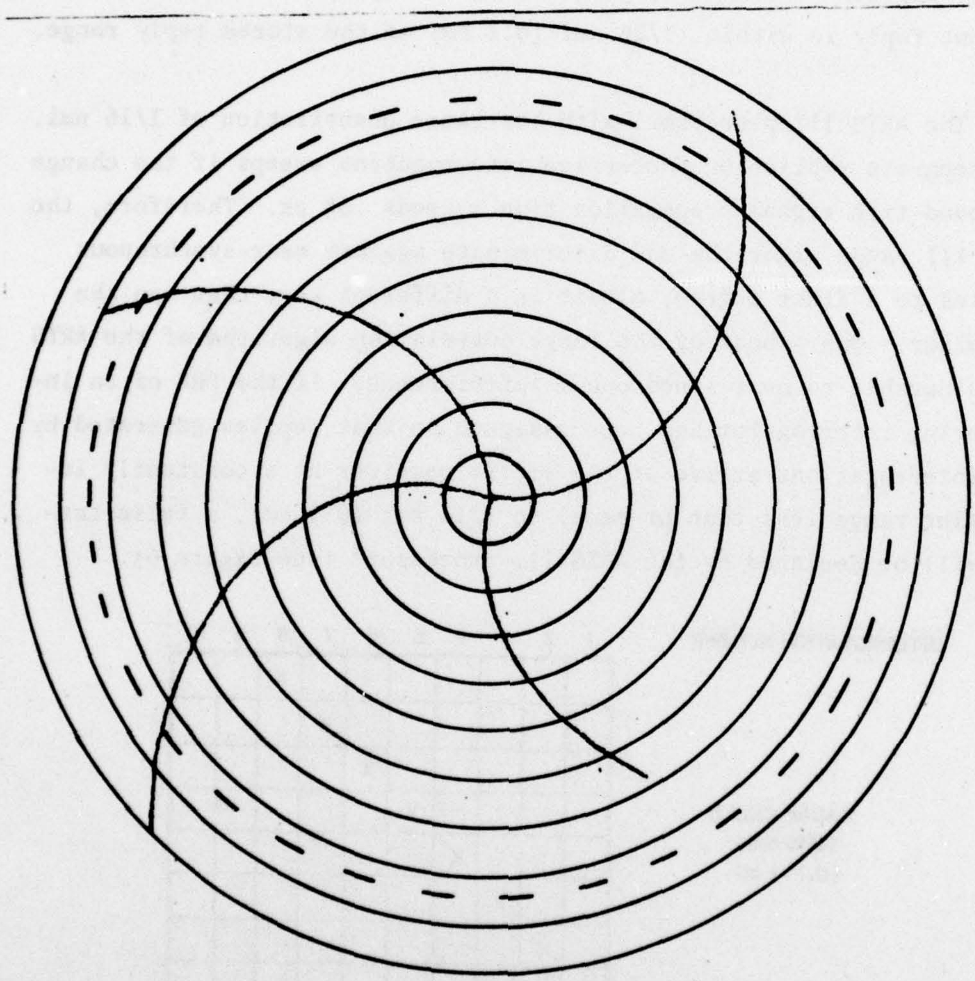

Figure 5. Spirals caused by 1 μs PRP separation, defruited video.

The critical factor in an analysis of the ability of a statistical processor to combat near-synchronous interference is the range-correlation algorithm. In the ARTS, after each interrogation, the replies are stored in a table in range order. After each succeeding interrogation, the incoming reply range is compared, in range order, to the stored replies. A check is performed to determine if the range of the current reply is within ±1/16 nmi (0.1 km) of the stored reply range.

The ARTS III processor, with its range quantization of 1/16 nmi, can separate replies on successive interrogation sweeps if the change in round-trip signal propagation time exceeds .68 μs. Therefore, the ARTS III range algorithm can discriminate against near-synchronous replies to a finer degree, albeit in a different way, than can the defruiter. One aspect of the range correlation algorithm of the ARTS is vulnerable to near-synchronous interference. If the PRF of an interfering interrogator has been assigned so that replies generated by its interrogations arrive at the victim receiver at a constantly increasing range less than or equal to 1/16 nmi (0.1 km), a false target will be declared by the ARTS III processor[3] (see Figure 6).

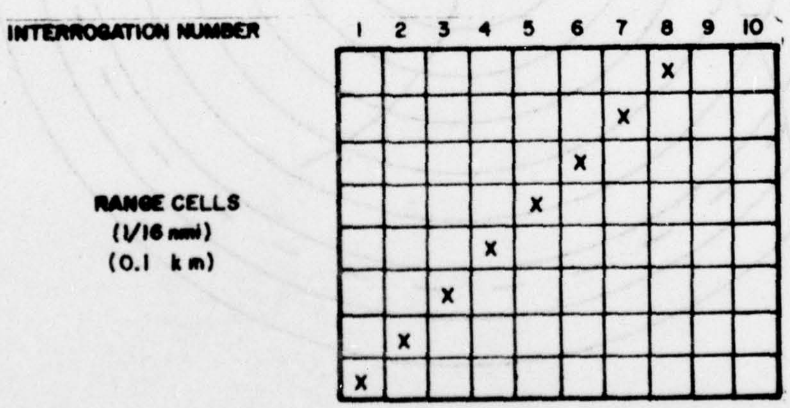

Figure 6. Near-synchronous replies, ARTS III.

[3]Holtz, Martin, *Test and Evaluation of the Level I Beacon Automated Radar Terminal System (ARTS III)*, FAA-RD-73-182, Federal Aviation Administration, January 1974.

Beacon anomalies caused by near-synchronous interference are aggravated by the presence of background fruit. The background fruit resulting from non-synchronous replies generated by other interrogators in the coverage area can fill in holes in near-synchronous reply sequences that would not otherwise result in false targets. This problem, of course, increases in areas of high-density fruit.

AN/FYQ-49 Common Digitizer

The common digitizer (CD) is the beacon processor used at FAA en route radar sites and processes only undefruited video. The quantization of the target detection unit used with the CD is 1/4 nmi (0.4 km). Replies can shift in range up to 1/4 nmi from sweep-to-sweep and be processed by the CD as part of the same target. This range shift is equivalent to a 3-μs change in round-trip signal propagation time.

It is apparent that interrogators with PRP's separated by up to 3 μs can generate consecutive replies that will be accepted by the CD as part of a target. Once the returns from an interfering interrogator "walk through" a range bin of the victim CD, the contribution of the interferer to a false target declaration at that range is finished. Therefore, since the CD has fixed range bins, it will hold the target range within 1/4 nmi (0.4 km) per PRP rather than allowing the target range to spiral out at 1/16 nmi (0.1 km) per PRP, as does the ARTS III. However, the CD is more susceptible to interference from strictly non-synchronous fruit than is the ARTS, due to the rather coarse 1/4-nmi range bins. The size of the bins allows for a greater possibility of range splits than does the ARTS III processor.

UPLINK INTERFERENCE

Uplink interference caused by near-synchronous PRF's is defined as transponder lockout and is described above. Lockout can result in either a complete miss of a target or in an azimuth split, where the center of a target is locked out, leaving enough hits on either side of the beam to create two targets with short run lengths.

The length of a miss sequence caused by near-synchronous interference is determined by the size of the deadtime gate in the transponder and the PRP separation between victim and interfering interrogators. For instance, if the deadtime gate resulting from the decode of a sidelobe suppression pulse pair is 35 μs, then a PRP separation of 30 μs can result in a maximum of 2 replies being denied to the victim interrogator as the interrogators pass the same transponder (Figure 7). Mainbeam overlaps result in longer transponder deadtimes and, therefore, longer miss sequences. Although such occurrences are rare, more complicated miss sequences can arise from PRF's that are multiples of other PRF's. An example of this is an interferer's PRF that is exactly one-half that of the victim. In this case, when both interrogators request replies from the same transponder, every other reply can be lost to the victim. With a number of interrogators covering the same airspace, complicated miss sequences can arise as a result of a combination of PRF's with varied relationships to the victim.

Defruiter/Decoder

The impact of transponder lockout on beacon processing is greater when a defruiter is being used. Since the defruiter requires a stored video pulse at the same range as an incoming pulse in order to pass the incoming pulse to the output, it will miss two returns in a row if a reply is missing.

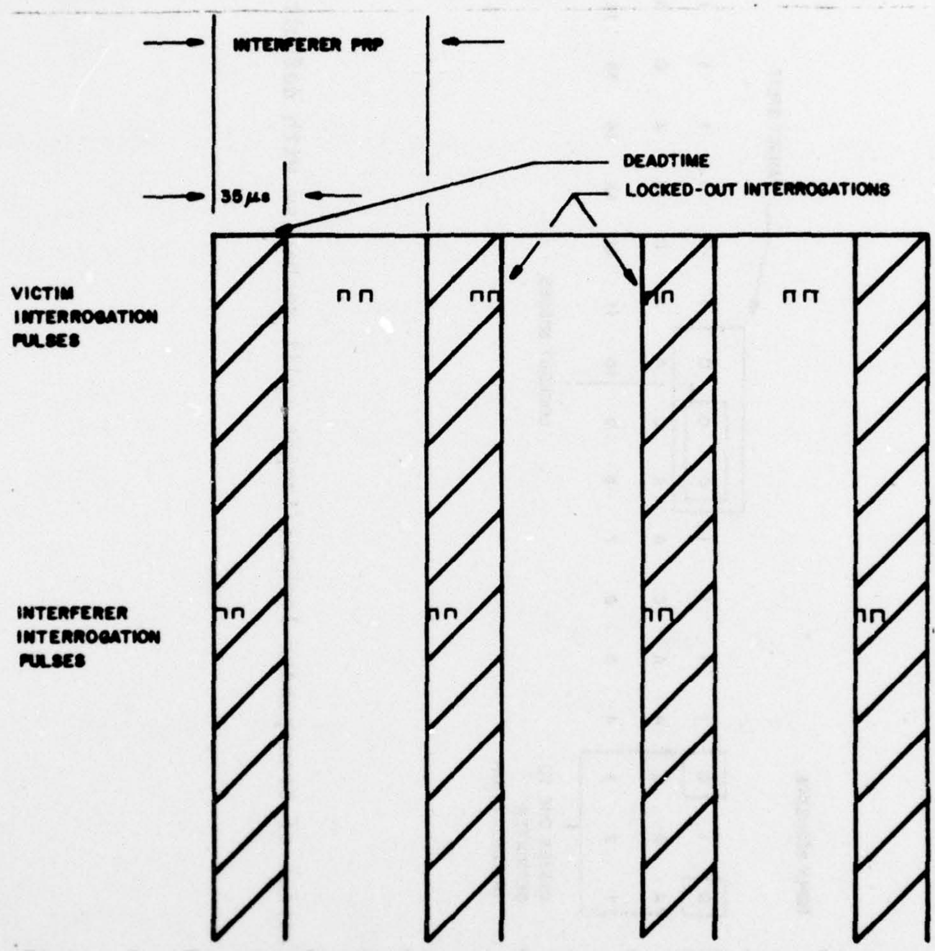

Figure 7. Transponder lockout mechanism for SLS interference.

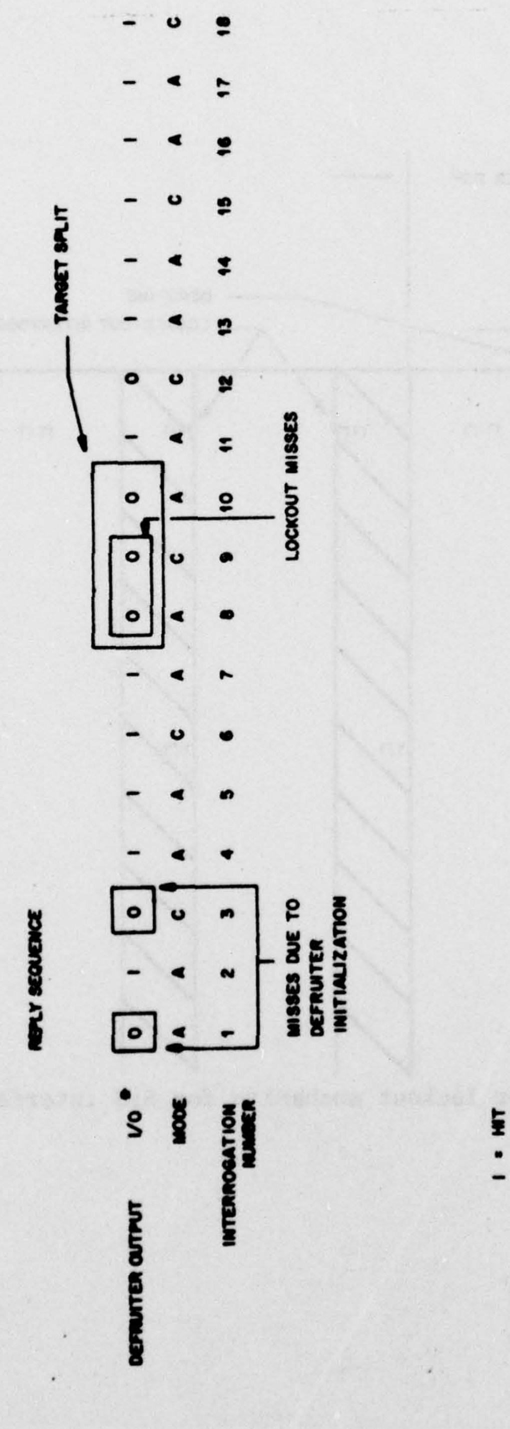

Figure 8. Illustration of transponder-lockout/target-split mechanism with definition.

For instance, the defruiter will always lose the first reply in a reply sequence, since there is no reply in storage. If modes are interlaced as in an A, A, C interlace, the first mode-A and the first mode-C reply will be lost in the defruiter. The same principle applies to aggravate the problem of transponder lockout. An example of this type of interference is shown in Figure 8. The figure displays a hit/miss sequence for a terminal interrogator with a mode interlace of A, A, C where replies numbered 8 and 9 have been missed due to transponder lockout from an interferer. Defruiter action caused replies numbered 1, 3, 10 and 12 to be lost. As can be seen, the reply sequence starts off weakly due to defruiter action and 4 of 5 hits are lost in the middle of the target due to a combination of transponder lockout and defruiter action. With the decoder as the processing unit, the visual display in this case could be quite confusing to the controller. As explained earlier, transponder lockout caused by suppressions triggered by the sidelobes of an interferer with a PRP separated from the victim by up to 35 μs can result in 2 missed replies at the victim. It can be seen that even short miss sequences such as that shown in Figure 7 can result in azimuth splits when defruited video is employed.

ARTS III Processor

The ability of a statistical processor to deal with miss sequences caused by transponder lockout is determined by the target-detection parameter settings. A series of misses out of a nominal 18 hits per beamwidth for the ARTS III can result in three types of errors in the target detection mechanism.

The first type of error occurs when a long series of misses prevents the target from being detected by the ARTS. Assuming that 18 hits are potentially available and that 7 hits are required for a valid target (a typical value, per Reference 3), 12 hits would

have to be missed for the target not to be detected. If the ARTS III in this instance was processing defruited data, then on the average, 9 replies would have to be missed due to transponder lockout while defruiter action eliminated 3, for the target to go undetected (see Figure 8 for a similar case). If undefruited video is fed to the ARTS, all 12 hits would have to be missed via lockout. Assuming a deadtime gate of 35 μs, the PRP separation between interrogators would have to be less than 5 μs in order for 9 hits to be locked out. In the case of a mainbeam overlap, and 60 μs deadtime, a PRP separation of less than 8 μs would be required in order for 9 hits to be missed. The PRP separation required to produce a missed target is, of course, reduced when defruiter action is not contributing to the number of missed replies. For instance, the PRP separation in the latter case must be less than 6 μs, in order for the necessary 12 hits to be lost.

The second type of error that can occur is simply an abbreviation of the run length of the target so that, although the target can still be detected by the ARTS III algorithm, the mode-A or mode-C code validation capability may be degraded. The ARTS III code validation process requires only back-to-back matching codes for the highest level of validation for any mode. However, this process does not begin until leading-edge threshold has been reached, and if the target has been reduced in length to 8 or 9 hits by lockout and defruiter action, the probability of code validation is reduced.

A major problem attributable to transponder lockout is azimuth splits. An azimuth split occurs when a string of replies is not received in the middle of a target, so that the processor declares two leading-and trailing-edges. Two targets are then declared at the same range, with the centermarks of the targets displaced

slightly to either side of the actual target azimuth. The frequency of occurrence of azimuth splits is conditioned by the ARTS detection parameter which determines *target end*. After declaration of the target leading-edge, the number of consecutive misses required for target end is typically 3 or 4 (Reference 3) for a 2:1 mode interlace (e.g., A, A, C, A, A, C). The case of 3 or 4 consecutive misses required for target end can occur as a result of transponder lockout, particularly when defruited video is employed. To get 3 consecutive misses when a defruiter is in use requires that only 2 replies be lost due to lockout. Considering the deadtime gate of 35 μs generated by a sidelobe-suppression pulse-pair decode, the PRP separation between two interrogators with constant PRF's would have to exceed 35 μs to circumvent the possibility of an azimuth split.

AN/FYQ-49 Common Digitizer

Analysis of the effect of uplink near-synchronous interference on the performance of the common digitizer (CD) is similar to analysis of the ARTS III. Both systems employ statistical processors that obtain a target leading-edge and trailing-edge and require a specified number of hits to declare a target. The algorithms are slightly different in that the CD employs a sliding-window detector of constant length while the ARTS III uses an expanding window and maintains several counters concerning the status of the target.

The en route system has in most cases been outfitted with the NADIF[a] antenna. The narrow beam of this antenna has reduced the number of possible returns from a transponder to approximately 30.

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[a]NAFEC Dipole Feed.

Only 20 of these returns are used for target detection on a 2:1 interlace as the CD uses only mode 3/A replies for that purpose. The length of the sliding window is set at 11 bits with the target leading-edge normally at 6 hits and the trailing-edge typically set at 2 hits. For the number of hits in the window to be reduced to 2, and consequently for *target-end* to be declared, 9 mode-3/A hits must be lost as a result of transponder lockout or some other cause.

Therefore, for an azimuth split to occur as a result of lockout caused by a single interrogator, the PRP of the interferer would have to be separated from the victim's PRP by less than 6 μs. (See Figure 7 for a similar case.) The above example assumes a mainbeam overlap (60 μs deadtime) and a 3/A, 3/A, C mode interlace transmitted by the victim interrogator. It may be misleading to assume from this discussion that the probability of the occurrence of an azimuth split is greater for ARTS III processing than for the CD. While more interrogations must be locked out for a target split in the en route system, the larger coverage area and the greater number of interrogations which interact with an en route site increase the likelihood of transponder *lockout*.

Since the common digitizer is not normally used with a defruiter, difficulties with code validation can arise that are not as prevalent with the ARTS III. The large amounts of non-synchronous fruit that are received in the en route system aggravate the code validation problem. Also, the *near-synchronous* reply overlaps that occur between interrogators with PRP's separated by less than a reply message length, complicate the problem of separating valid from invalid replies.

METHODS FOR MINIMIZING NEAR-SYNCHRONOUS INTERFERENCE

PRF Separation Criteria

The most important factor to consider in PRF assignment is minimum separation of pulse repetition periods between sites in the same coverage

area with constant interrogation rates. Practical considerations dictate that an absolute criterion of this sort may not always be achievable. As a starting point, however, specification of minimum PRP separation can be used to establish bounds within which a certain degree of interference must be expected.

Interference resulting from transponder lockout, or uplink interference, occurs between interrogators with relatively greater separation in PRF's than those subject to downlink interference. The reason for this is simply the size of the interference gate. The largest interference gate for the generation of false targets on the downlink is the 1/4-nmi range bin of the common digitizer. This 1/4-nmi (0.4 km) range bin represents only a 3-μs change in round trip signal propagation time. The range correlation gate for the ARTS III processor is ±1/16 nmi (0.1 km), for which a PRP separation of less than 1 μs is required for false target generation. It was demonstrated earlier that, although FAA defruiters correlate from pulse-to-pulse within a 1-μs acceptance gate, PRP separation of up to an SIF reply length (≈ 25 μs with the SPI[a] pulse) can result in interference pulses passing the defruiter.

The largest interference gate is the deadtime gate in the transponder. The ranges of the deadtime gate are described in Section 2. Nominal sizes of the gates are 35 μs after the decode of a P_1 P_2 *sidelobe suppression* pulse pair and ≈ 60 μs after the decode of a valid P_1 P_3 interrogation pulse pair.

Figure 7, taken in conjunction with the discussion of azimuth splits within the ARTS III processor, established a case for a minimum PRP separation of at least 35 μs. The following conditions taken jointly will generate the azimuth splits:

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[a]Special-purpose identification.

1. SLS decode of the interferer pulse pairs by the transponder

2. PRP separation of less than 35 μs between the victim and the interferer

3. Defruited video employed by the victim

4. ARTS III target detection criterion set to 3 consecutive misses for target end.

As the PRP separation between the victim and the interferer decreases, thus resulting in an increased number of missed replies, steps 3 and 4 are no longer required for an error to occur. Assigning PRF's that would maintain a PRP separation of at least 35 μs would greatly decrease the probability of occurrence of an azimuth split resulting from transponder lockout. While an azimuth split could still occur for mainbeam overlaps between the interferer and the victim, the occurrence of azimuth splits caused by the sidelobe suppression mechanism would be eliminated. It has been demonstrated in a previous ECAC report that the average probability of mainbeam overlap in the Miami, Florida area ranges from approximately 0.0001 to approximately 0.005.

In addition to providing protection against azimuth splits, a PRP separation criterion of 35 μs would virtually eliminate all of the other forms of near-synchronous interference that were discussed previously except mainbeam overlap lockout. The interference gates for each type of downlink interference are significantly smaller than the 35-μs separation criterion.

Distance Separation

The coverage area of responsibility for FAA interrogators is nominally 200 nmi (320 km) for en route sites and 60 nmi (96 km) for terminal sites. The actual radius covered by a site may vary

somewhat from these figures. A report under ECAC Task 20-b.1 analyzes the coverage of the JFK air-route surveillance radar (ARSR). The equipment characteristics and assumptions used for these calculations are listed in TABLE 1. The large (28 dBi) mainbeam gain of the NADIF antenna can extend the coverage out to beyond 200 nmi (320 km), even coupled with recent power reductions. In the process of determining a minimum distance separation requirement between sites with the same PRF, this factor should be considered.

TABLE 1

EQUIPMENT CHARACTERISTICS AND ASSUMPTIONS FOR JFK ARSR COVERAGE[a]

JFK ARSR/ATCRBS site	NADIF antenna
Power, interrogator	560 W, peak
Mainbeam Gain, interrogator	28 dBi
Aircraft Antenna Gain, transponder	-4.3 dBi (Boeing 727 average)
Transponder Receiver Sensitivity	-69 dBm
Aircraft Altitude	50,000 feet (15,240 meters) maximum

[a]Terrain effects included.

The difficulty in developing a general distance-separation criterion for the ATCRBS arises from the fact that the coverage area varies from site to site. Efforts have been made from within the FAA to reduce power at sites that are overpowered, and beacon coverage has been reduced to the minimum range necessary to meet surveillance requirements.

For sites with the same PRF, caution should be exercised so that an overlap of their surveillance requirements does not occur. More specifically, en route sites with the same PRF should be a minimum of

400 nmi apart. Terminal sites should be at least 120 nmi (192 km) apart from this condition, and any combination of the two (terminal and en route) should be located no closer than 260 nmi (416 km). The above criteria are based on the sum of the mainbeam coverage areas.

It is recognized that the PRP separations and distance separations described above may be impossible to achieve. A compromise is suggested here for those pairs of sites which have PRP's that are separated by less than 35 μs. That is, separation of two sites by a distance equal to the sum of the mainbeam coverage of the victim plus the omnidirectional antenna coverage (sidelobe suppression coverage) of the interferer will avoid most of the interference possibilities. The maximum omnidirectional coverage of the FA-8044 antenna at the JFK ARSR is ≈ 23 nmi (≈ 36.8 km). The required separation between the JFK ARSR and another en route site would then be 223 nmi (356.8 km).

PRF Stagger and PRF Jitter

PRF jittering evolved because of the desire to eliminate second-time-around targets. The amount of jitter involved is usually on the order of a few microseconds. Jitter can be effective in removing the near-synchronism which causes downlink interference in the form of false targets, but the size of the jitter is too small to have much impact on transponder lockout. The interference gate in the lockout case is on the order of 35 μs and a jitter of 2 or 3 μs on an interrogation sweep will not greatly affect the lockout sequence.

Staggering of PRF's is an effective way of dealing with near-synchronous interference. The relatively large shift in PRF from sweep-to-sweep and the length of the stagger sequence provide a significant degree of freedom from near-synchronous interference, both on the uplink and the downlink. A typical stagger sequence is

as follows: 554, 530, 436, 350, 447, 542, 525, 320 interrogations per second. The beacon is staggered when tied to the ASR-7 (see Section 2).

Target Detection Parameters

TABLE 2 lists 12 sets of target detection parameters used with the ARTS III processor. The first 6 columns are for mode 3/A targets only, and the second set of 6 are for modes 3/A and C targets. Reference 3 contains an evaluation of the effectiveness of each set of parameters in the areas of target detection, false alarm rates, and code validation. On the basis of the considerations in these three areas, Reference 3 recommends the use of detection-parameter set no. 6 of TABLE 2 for both mode 3/A and modes 3/A, C targets.

The distinguishing characteristics of detection-parameter set no. 6 for modes 3/A and C targets are a short (5 hits) run length for detection of a valid target and a requirement of 3 consecutive misses (after target leading-edge) to declare target trailing-edge. In addition, only 2 hits are required to start a target. Detection parameter set 6 for mode 3/A targets is similar to set 6 for modes 3/A,C targets except that the number of consecutive misses for *target end* is 4 while no mode C returns are expected, and a valid target is declared on only 4 hits.

While detection-parameter set no. 6 may provide the best average combination of probability of target detection, probability of false alarm and probability of code validation, it does not discriminate well against near-synchronous interference. From the standpoint of downlink near-synchronous interference, the leading-edge criterion of only 2 hits does not guard well against the start of a near-synchronous induced false target. Since the ARTS is only provided with approximately 18 hits in a beamwidth, a leading-edge criterion as

TABLE 2

ARTS III DETECTOR THRESHOLD PARAMETERS

Description	Mode 3/A Parameter Values Detection Parameter Set No. 1	2	3	4	5	6	Mode 3/A and C Parameter Values Detection Parameter Set No. 1	2	3	4	5	6
Number of consecutive misses prior to T_L to discard a record as fruit	3	3	4	4	4	4	2	2	3	3	3	3
Number of hits required to declare T_L	3	2	2	2	2	2	3	2	2	2	2	2
Number of consecutive misses after T_L to declare T_T	5	5	4	4	4	4	4	4	3	3	3	3
Minimum number of hits required to class a record as a valid target	5	5	4	5	3	4	7	7	6	7	4	5
Minimum number of interrogations which must be observed before T_T can be declared	20	20	15	15	15	15	20	20	15	15	15	15
Number of hits to declare a strong target	9	9	8	8	8	8	13	13	9	9	9	9

T_L = target leading-edge declaration.

T_T = target trailing-edge declaration.

large as that used by the CD may be unreasonable, but a larger threshold than 2 hits would provide better false target protection, particularly in an environment containing near-synchronous interference and large amounts of non-synchronous background fruit.

The major problems with detection-parameter set no. 6 with regards to near-synchronous interference are 1) only 3 misses to end the target, and 2) only 5 hits to declare a valid target. The selection of these parameters makes it easy for the azimuth splits described earlier to occur. The 5-hit requirement leaves enough hits on either side of the lockout/defruiter action (e.g., Figure 7) for two targets to be detected. Increasing the number of hits required to declare the target would not alleviate the problem. If the number of hits for target declaration were increased to 6, for instance, only one target would be detected (Figure 7). However, this target would be shifted from the actual target center, and thus would have a large centermark error. The best method for alleviating the problem of target splits would be to increase the number of consecutive misses required for *target end* from 3 to 4. This change would require an additional reply to be locked out for a split to occur.

Range-Correlation Algorithms

The deficiency in the ARTS III range-correlation algorithm with respect to near-synchronous interference was pointed out earlier in this section and displayed in Figure 6. The algorithm compares the incoming reply range with the range of the last-received reply. If replies generated by a near-synchronous interferer arrive at the victim within the 1/16-nmi (0.1 km) range bin of the ARTS, they will continue to be accepted as part of the target on each succeeding interrogation sweep.

An alternative to this algorithm is suggested in Reference 3. A running average of the reply range would be maintained for comparison with the incoming reply range. This method would prevent the *spiralling out* of the target, which can occur using the present method. Also recommended in the same report is that the size of the range bin be reduced to ±1/32 nmi (0.05 km). This, of course, narrows (by one-half) the separation between PRP's required for false target generation.

The major deficiency in the CD range-correlation method is the size of the range bins. The 1/4-nmi (0.4 km) range bin requires much larger PRP separations than does the ARTS to avoid acceptance of undesired replies on consecutive sweeps. In addition, the size of the range bins allows for greater acceptance of non-synchronous fruit. Reducing the size of the range bins would improve CD performance in this respect.

Receiver Sidelobe Suppression (RSLS)

Receiver sidelobe suppression (RSLS) is a method that eliminates replies received on the sidelobes of the antenna pattern. A comparison is made between the signal levels received on a directional pattern and a control pattern, and when the signal received on the difference pattern is stronger than a specified threshold level (3 to 15 dB down from the sum pattern) the signal is rejected as being a sidelobe reply.

Reductions in the fruit rate provided by RSLS would assist in discriminating against near-synchronous interference. Fruit rate reductions of up to 90% will occur with the implementation of RSLS.[4] Reference 4 also concludes that the incidence of *mainbeam killing*, or the rejection of valid mainbeam replies caused by strong sidelobe signals, is very low.

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[4]Lerner, D. S. and Yarnall, W. M., *Receiver Sidelobe Suppression Study*, Lockheed Electronics, DOT-FA-74NA-1027, June 1974.

RSLS would provide a method whereby large amounts of fruit, including near-synchronous fruit, can be eliminated before processing. Fruit reduction of this type provides an alternative to the defruiter without the expense of lost replies due to defruiter action. However, near-synchronous replies received in the mainbeam would not be removed from processing.

SECTION 4

MODEL DESCRIPTION

The most frequently occurring form of near-synchronous interference is *transponder lockout*. The reason for this is simply that the interference gate set up by the transponder deadtime is much larger than the gate which exists for FAA reply-processing equipment. Since transponder lockout affects performance of interrogators with greater separations in PRF than does the downlink interference mechanism, it follows that logical assignment of PRF's to avoid the deleterious effects of transponder lockout will also minimize the impact of near-synchronous replies on processor performance. The above assumption was the basis for the development of the PRF selection model. The decision mechanism of the model is based on a collection of statistics generated by an analysis of the mathematical interrelationships between PRF's.

Fundamentally, the model accepts as input a group of periodic functions (the pulse-repetition-period sequences) and establishes the simultaneous occurrence of interrogations that occur over a period of simulation. The term *simultaneous occurrence* is defined here as the arrival of an interrogation pulse-pair at the transponder within the deadtime period generated by a sidelobe suppression or a valid interrogation. Antenna characteristics of the interrogator sites under consideration are also among the inputs to the model. These inputs include the antenna rotation rate and the mainbeam width, since the area of concern is those replies that are lost in the victim mainbeam.

TABLE 3 lists the inputs to the model. The number of victim interrogations simulated is a compromise between minimal statistical error and excessive computer run time. The amount of deadtime generated by an interferer pulse-pair is determined by the pointing angle of the interferer's antenna at the time of transmission. A worst-case condition is assumed in

this respect, in that all interrogators within a nominal range of the point of interest are considered as interacting with the victim.

TABLE 3

MODEL INPUTS

Length of Simulation
Deadtime Generated by a Valid Interrogation
Deadtime Generated by a Sidelobe Suppression Pulse-Pair
Pulse Repetition Periods
Stagger Switch/Stagger Sequences
Jitter Switch/Jitter Sequences
Antenna Mainbeam Widths
Antenna Sidelobe Widths
Antenna Scan Rate

Stagger sequences of variable length will be accepted by the model as input. A random number generator is used to trigger the operation of any sites that use the random jitter method of transmitting interrogations. The antenna beamwidths are used along with the scan rate of the antenna to determine whether the transponder of interest is receiving P_1 P_3 or P_1 P_2 pulse pairs.

MODEL INPUTS

To obtain useful results from the PRF model, it is important that the exact PRF's of all the interrogators involved be known. Relatively small changes in PRF can have a significant impact on the operation of the system and the model.

A victim interrogator is selected and a determination is made of those interrogators that will interact with the victim. The determination is made based on the coverage area of the interrogators involved. The distance separation criteria developed in Section 3 are used for this purpose. In addition, those interrogators whose SLS pulses will not interact with the mainbeam of the victim are indicated in the input. This notation is made for those interferers separated from the victim by a distance greater than or equal to the coverage area of the victim mainbeam plus the coverage distance of the omnidirectional antenna used with the interferer. The basic criteria for selection of the interrogator environment are as follows:

1. Select all en route beacons within 400 nmi (640 km) of the victim.
2. Select all terminal beacons within 260 nmi (416 km) of the victim.
3. Note all interrogators selected further than 223 nmi (356.8 km) from the victim as being outside of sidelobe range.

The above figures are based on the analysis in Section 3 and assume that the victim is an en route beacon. For a terminal beacon as the victim, all range selects should be reduced to correspond to the 60-nmi (96-km) coverage area. Fewer interrogators will interact with a terminal site because of its reduced coverage area.

MODEL OPERATION

The model operates as follows:

1. Model inputs are read in; these include deadtimes, PRF's, and antenna characteristics.
2. The first test PRF for the victim interrogator is read in.

3. A subroutine is called that increments each interrogator's antenna azimuth by an amount determined by its rotation rate.

4. The interrogation times of each beacon are pseudorandomly initialized, and are incremented by the value of the PRP.

5. The interrogation time of the victim is compared to the interrogation times of each interferer.

6. The portion of the interferer antenna pattern that is scanning the transponder of interest is checked to determine if a P_1 P_3 pulse pair is present or if a P_1 P_2 pulse pair is present.

7. The amount of deadtime assigned to the transponder at that point corresponds to whether a valid interrogation or a sidelobe suppression pulse pair has been decoded.

8. The difference between the interrogation arrival times is checked to see if a victim P_1 pulse arrived within the deadtime gate of the transponder.

9. If a victim pulse pair has been locked out, a check is made to determine if the victim signal was a P_1 P_3 pulse pair from the mainbeam.

10. The simulation continues through the loop, checking victim interrogation time against the arrival times of each of the interferers, until the specified number of interrogations has been checked.

11. Throughout the above simulation, a series of counts are maintained as output for the model.

12. The first count contains the total number of mainbeam sweeps the victim makes past the transponder of interest.

13. The second count contains the total number of victim mainbeam interrogations that were locked out by the interferers.

14. The total number of missed replies is divided by the mainbeam sweep count to show the average number of misses in the mainbeam.

15. A third count is the total number of groups of two or more missed replies. This count indicates the number of times that

a pair of misses, not necessarily back-to-back, occurred within the same victim mainbeam sweep.

16. A count of the total number of misses in these groups is used with the above information to calculate the average number of misses in mainbeam miss groups of two or more.

17. Finally, a count is made of the total number of consecutive miss groups of two or more. This count is defined as the instance where at least two back-to-back replies are missed from a victim mainbeam sweep. The total number of misses in these consecutive miss groups is used with the above information to calculate the number of misses in each consecutive miss group.

The printed output from the simulation consists of the collection of statistics described above. The outputs are summarized in TABLE 4. The PRF selection model is available to the FAA for their use in making PRF assignments.

TABLE 4

MODEL OUTPUTS

Average Number of Misses in the Mainbeam
Total Number of Misses in the Mainbeam
Number of Mainbeam Sweeps
Average Number of Misses in Miss Groups of Two or More
Total Misses in Groups of Two or More
Number of Occurrences of Miss Groups of Two or More
Average Number of Misses in Consecutive Miss Groups
Total Number of Consecutive Misses
Total Number of Consecutive Miss Groups

SECTION 5

CONCLUSIONS AND RECOMMENDATIONS

CONCLUSIONS

1. The predominant form of near-synchronous interference is transponder lockout.

2. Maintaining a 35-μs separation in pulse repetition periods (PRP's) between interrogators with overlapping coverage requirements will greatly reduce the probability of near-synchronous interference.

The following factors contributing to these conclusions were found during the analysis:

Although the acceptance gate of the defruiter is on the order of ±1 μs, PRP separations of as much as a reply length can result in unwanted pulses passing the defruiter.

The range-correlation algorithm of the ARTS III processor allows near-synchronous replies, whose arrival times are spaced such that they appear less than ±1/16 nmi (0.1 km) apart, to form a false target.

The large range bins of the common digitizer allow for replies shifted in range by as much as 1/4 nmi (0.4 km) to be accepted as part of the same target. The size of the range bins in the CD also contributes to the number of range splits experienced in the CD target display.

Transponder lockout resulting from near-synchronous interference causes broken targets to be displayed after processing, regardless of whether a decoder or a statistical processor is used.

Defruiter action increases the number of replies lost to transponder lockout, thus increasing the probability of an azimuth split declaration by the ARTS III processor, or a broken target in the analog system.

RECOMMENDATIONS

1. Assign PRP's so that a minimum separation of 35 μs is maintained for interrogators in the same coverage area.

2. Verify that the PRF capability of new primary radar equipment is compatible with beacon requirements, as stated above.

3. Maintain distance separation of interrogators with the same PRF by at least the sum of their mainbeam coverage radii. This distance should be 400 nmi for en route sites, 120 nmi for terminals, and 260 nmi between en route and terminal sites (640, 192, and 416 km).

4. Eliminate use of the defruiter with the ARTS III in areas where fruit densities do not overload the processor.

5. Implement staggered PRF's for the beacon, where possible.

6. Assign ARTS III target-detection parameters to discriminate against transponder lockout. (See Section 3.)

7. Modify the ARTS III range-correlation algorithm to maintain a running average of the target range, to prevent spiralling of the target.

8. Implement receiver sidelobe suppression (RSLS) to reduce the amount of fruit replies received in the sidelobes and thereby reduce the probability of false target generation, where the need is justified.

9. The PRF selection model developed by ECAC should be used to assist in the assignment of a beacon PRF to individual interrogators.

REFERENCES

1. Crawford, C. R., *Computer Simulations of ATCRBS Processing Equipment for Use with the AIMS and Transient Effects PPM's*, FAA-RD-76-102, ECAC, Annapolis, MD, January 1976.

2. *U.S. National Standard for the IFF Mark X (SIF) ATCRBS Characteristics*, FAA Order 1010.51A, Federal Aviation Administration, Washington, DC, 8 March 1971.

3. Holtz, Martin, *Test and Evaluation of the Level I Beacon Automated Radar Terminal System (ARTS III)*, FAA-RD-73-182, Federal Aviation Administration, January 1974.

4. Lerner, D. S. and Yarnall, W. M., *Receiver Sidelobe Suppression Study*, Lockheed Electronics, DOT-FA-74NA-1027, June 1974.